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ABSTRACT

An adaptive instructional strategy for individualized concept teaching was developed according to decision processes that adjust instructional variables to individual differences and differential performance, either before a task in response to an individual's traits or during a task in response to his current responses. An adaptive instructional strategy is presented for teaching concepts according to a learner's error response pattern after an intermediate evaluation with the instructional sequence. (Author/RH)

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TECH MEMO

ADAPTIVE INSTRUCTIONAL MODEL FOR CONCEPT ACQUISITION

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ABSTRACT

An adaptive instructional strategy for individualized concept teaching is represented by paradigms designed according to decision processes that adjust instructional variables to individual differences and differential learning performance. The basic variations of the strategy are of two functional classes: pretask and within-task variables. Pretask variables include individual trait difference and treatment variables; within task-variables provide for manipulation of such things as the number of examples, the degree of prompting and difficulty, and the type of feedback/correctional process based on individual state criteria. The pretask procedure adapts the presentation to the learner's entering trait capabilities, while the within-task presentation is self-modifying because adaption is to the learner's current response pattern and state levels.

Presented is an adaptive instructional strategy for teaching concepts according to a learner's error response pattern after an intermediate evaluation within the instructional sequence: a General Adaptive Model and a Specific Adaptive Model. The General Model would reduce learner concept errors by using a predetermined program based upon type of error committed. The Specific Model would further reduce concept

errors by using an individualized strategy based on type and degree of errors. The Specific Adaptive strategy should have direct application for many of the computer-based instructional programs currently being developed in educational and training instititions. The General Adaptive strategy could be applied in branching programed texts, and by an instructional manager in an individualized instructional program.

Adaptive Instructional Model for Concept Acquisition[1]

Robert D. Tennyson
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The individualization of the learning process represents a challenge to the instructional designer and researcher. An instructional system is needed that is designed for mass usage, but which allows for unique environments for the many learner characteristics. Instructional science implies designing the environment to account for individual characteristics based on a system that adapts to those differences. This paper presents an adaptive instructional model for concept teaching which incorporates the humanistic ideal of self-learning.

Adaptive concept acquisition (ACA) models are represented by instructional paradigms designed according to decision processes that adjust instructional variables to individual differences and differential learning performance. For the purpose of the adaptive concept acquisition models, the basic variations proposed are of two functional classes: pretask and within-task variables. Pretask variables are composed of individual difference and treatment variables, such as ability and problem difficulty. These variables serve to set limits on the instructional alternatives available, and the media to be used for instruction. In the second class, within-task variables provide for the manipulating the number of examples, the degree of prompting, and the nature of

[1]The instructional model discussed in this paper was designed under U.S. Air Force contract No. F33615-71-C-1277, "The Analysis and Development of an Adaptive Instructional Model(s) for Individualized Technical Training." A computer simulated program of the model was developed to determine its feasibility for use in the Air Force's Advanced Instructional System.

the feedback/correctional process based on individual state criteria. Thus, the flexibility of the ACA models are distinguished by the varying levels of adaptability. In an educational context, this means that the model can be modified to reflect the diversity of concepts being taught. The complexities of the targeted concepts should determine the degree of adaptability to individual differences.

Literature Review

Instruction is a process of manipulating the environment to produce a desired change in a learner's behavior. An early attempt to solve the problem of individual differences was grouping or tracking of students by grades or by scores from ability tests. This homogeneous grouping had little effect because the groups seldom received different kinds of instruction. Different areas of education incorporated Skinner's (1954) linear programmed instruction which allowed students to progress at their own rates. This procedure emphasized that individuals do function at different learning rates. However, the material itself was not individualized since all students received the same instructional sequence. The influx of technology influenced Crowder's (1959) procedures of intrinsic programming with provisions for branching able students through the same material more rapidly than slower students who received remedial frames whenever a question was missed. This type of programmed instruction was not widely used in education's instructional situations because of the difficult developmental task which required review sections for each alternative answer (M. D. Merrill, 1971).

There are two basic procedures for designing concept acquisition instruction which would have adaptive capabilities extending from the above assumptions. The first involves the use of premeasure(s) (such multiple variables as aptitudes, personality variables, anxieties, etc.) for diagnosing the learner's behavior and, then, prescribes a specific learning task designed to adapt to these individual differences. The second requires intermediate evaluations of the learner's progress and assigns adaptive segments to correct errors in acquisition.

Pretask adaptation. Cronbach (1967) suggests that if development in a wide range of persons is to be facilitated, a wide range of environments suited to the optimal development of each individual must be offered. Instructional units covering available content in different formats or sequences would be adapted to differences among learners. Cronbach's model might prescribe one type of sequence and media for a learner of certain characteristics, while another learner of differing characteristics would receive an entirely different mode of instruction. The advantage of the ACA model over other systems is the flexibility of selecting conditions which would change according to concept content. In order to identify methods of prescribing optimal instructional strategies, Cronbach (1967) advocates that an extensive research program be conducted to identify those aptitudes which interact maximally with instructional treatments; this body of research has become known as aptitude treatment interactions, and has been abbreviated as ATI. Implicit in Cronbach's model is the assumption that specific instructional treatment assignments can be made from empirically determined measures existing prior to the onset of instruction. A further

assumption is that a regression model can be developed for the assignment of individuals to different instructional strategies.

Research studies (Tallmadge, Schearer, and Greenberg, 1968; Cronbach and Snow's review, 1969; Dunham and Bunderson, 1969; P. F. Merrill, 1970; Tennyson and Wolley, 1971) have investigated this assumption to determine if premeasured individual aptitudes interact with instructional treatment. These studies indicate that disordinal interactions (ATI's) have an elusive nature. Bunderson and Dunham (1970), in the final report of a three year research project on cognitive abilities and learning, challenged the ATI concept as a viable predictive procedure in "real world" instructional contexts. The reasons for their skepticism can be summarized as: (a) useful disordinal interactions are rare; (b) disordinal interactions are not sufficiently robust after minor changes in the task or population; (c) the benefit from disordinal interactions may be less than that attainable through revision of a single optimal treatment. They suggest that instead of seeking disordinal interactions in order to assign individuals to different macro-treatments, ATI's be used to revise the optimal treatment to reduce the learning burden of slow aptitude individuals. After the effectiveness of the single best treatment has been maximized using a systematic approach to instructional design (Bunderson, 1970; Briggs, 1970; Tennyson and Boutwell, 1971), micro-treatment variables can be applied adaptively in the instructional program rather than produce entirely different alternative treatments. This would use the most efficient sequence, the most appropriate media for display, and the most effective examples. Adaption within the program would then occur when learners deviated from the optimal program.

Within-task adaptation. The second procedure proposes adapting instructional strategy according to learner's response behavior in the learning program and to other current state characteristics. The within-task adaptation procedure is unlike Cronbach's approach because individuals are not assigned to different macro-treatments, nor are measures obtained prior to the entry of the individual into the instructional task employed. On the other hand, the within-task procedure differs from Crowder's approach in that Crowder utilizes only the last response made by the student in reaching an instructional decision. The within-task adaptive strategy would make instructional decisions from an updated history of the student's behavior during a segment of the concept learning tasks. Furthermore, the reliability of a pattern of responses compared to a single response should increase the validity of such adaptive decisions. In educational decisions on media and mode of instruction for particular units would depend on what is the most appropriate method of presentation. When learners deviate from the optimal sequence, they can be assigned corrective instruction. The within-task method of adaptation is such that remedial "hole patching" (Cronbach, 1967) is avoided on the basis of empirically validated instructional theory.

Individual difference variables may be classified as either trait or state variables. Trait variables may be characterized as states, long term indices which are descriptive of a learner's expected general behavior. State variables, in contrast, may be characterized as dynamic, short-term indices which are descriptive of a learner's behavioral response within a given specific situation. There is research

evidence (O'Neil, Hansen, and Spielberger, 1969; Leherissey, O'Neil, and Hansen, 1971; P. F. Merrill and Towle, 1971; Tennyson and Boutwell, 1972) that trait or state variables measured prior to a learning task are not as effective in predicting student performance as state variables measured during the actual learning of the task. These findings suggest that it would be possible to include state measures during the task to adapt instructional sequencing.

The within-task adaptation model is based on three assumptions: (1) there are a limited number of different kinds of behavior or types of learning (Gagné, 1970; M. D. Merrill, 1971); (2) there is an optimal group instructional strategy or paradigm based on the conditions of learning for each behavior level; and (3) individual performance can be optimized by making adaptations to the group instructional paradigm according to individual state response patterns.

Concept Acquisition. Mechner (1965) defined concept acquisition as the process of generalizing within a class and discriminating between classes. For example, in an electronics course students would have to identify certain types of wire schemes as being variations within a given wiring system, and at the same time discriminate between the systems. To teach this skill, Markle and Tiemann (1969) and M. D. Merrill (1971) postulated that concept acquisitions would result if examples used during instruction differed in the irrelevant attributes associated with each, that is, each kind of wiring system should be presented in many different colors, thicknesses, structures, etc. Such presentation promotes generalization within the class. Discrimination between classes is facilitated by presenting nonexamples which have irrelevant attributes

resembling those of the given examples; the various wiring systems would be nonexamples for the one system under instruction.

In testing for concept acquisition, it is vital (Mechner, 1965; Markle and Tiemann, 1969; Tennyson, 1972a) that the items on the test are previously unencountered, in other words, not used in instruction. A good set of items must have a number of other characteristics. In order to test for generalization across the total range of examples included in the concept, test items must cover the range specified by a thorough analysis of the concept. The number of examples the student can correctly classify is less important than the range of examples to which he can generalize. Discrimination of nonexamples can also be tested when the analysis of the concept has identified the key relevant attributes.

Tennyson, Woolley, and M. D. Merrill in a research investigation (1972) designed an optimal group instructional strategy for teaching concepts based on the theoretical work of Markle and Tiemann (1969, 1970), M. D. Merrill (1971), and Woolley and Tennyson (1972). The concept Tennyson et al. (1972) chose to teach was the metrical concept, "trochaic meter," as exemplified in poetry selections. As a preliminary estimate of range, they asked naive subjects to classify a large number of examples and nonexamples of the concept on the basis of a given definition. Some obvious examples were recognized by almost all subjects and were termed high-probability examples. Some nonexamples were equally obvious and were termed high-probability nonexamples. Examples which were difficult to recognize were termed low-probability examples; subtle discriminations, which could not easily be made on

the basis of the definition, produced low-probability nonexamples. They hypothesized that different combinations of these high- and low-probability examples and nonexamples would produce predictable errors in concept acquisition. Markle and Tiemann (1970) had proposed that restricting the range of examples would cause a student to undergeneralize, that is, to accept on a test only the same limited range provided in instruction. Tennyson et al. produced precisely this effect by giving subjects instruction which included the definition, only high-probability examples, and high-probability nonexamples. Markle and Tiemann also proposed that poor selection of nonexamples, in conjunction with a broad range of examples, would cause students to overgeneralize: to accept nonexamples as members of the class. This effect was produced by providing instruction including the definition and full range of high- and low-probability examples, and subtle discriminations taught by the low-probability nonexamples. The effect of a particular limitation on the range of examples, in which one salient but irrelevant attribute is always present, was also investigated. The attribute used was the Victorian origin of the selections. All examples of trochaic meter in this treatment were dated in the Victorian period, while nonexamples were selected from earlier or later periods. Despite the definition directing attention to the meter of the examples as the critical attribute, students showed a misconception on the test: they generalized correctly only to examples of trochaic meter written in the Victorian period. They rejected true examples from other stylistic eras and accepted some Victorian nonexamples. Tennyson, Woolley, and M. D. Merrill's (1972) data support the position that the selection of both examples and nonexamples

is an important item in effective concept teaching. A wide range of examples prevents undergeneralization, while a good selection of nonexamples prevents overgeneralization. In instructional development projects the Tennyson et al. model has application to the design of ACA instructional materials. The system provides a method for selecting instances and sequencing them to an optimal task. The component variables are uniquely adaptable to individual characteristics. Thus, they have the capabilities for within-task adaptation. For example, if a learner commits a classification error on an intermediate evaluation, the type and degree of examples and nonexamples can be adjusted to correct the error. The model also allows for designing a multiple entry program based on pretask measures. Learners with poor reading ability, for example, would enter the task with easier high-probability instances than someone with good reading ability.

Model Structure

The ACA instructional system incorporates standard individualization components of learning rate, self-pacing, providing on-line and off-line assistance, flexible utilization by the learner, remedial capabilities, review frames, enrichment material, and behavioral modification variables, such as, incentives, praise, and motivation. The two basic functional classes of the ACA models, pretask variables (set limits on the instructional alternatives) and within-task variables (modifiable alternatives), can be designed into two adaptive concept instructional sequences: a general adaptive model and a specific adaptive model.

Concept adaptive sequences. Upon completion of the initial segment, the student is tested, then presented an optimal instructional task.

The test performance is evaluated in relation to the three types of classification error (overgeneralization, undergeneralization, and misconception). If he reaches criterion, then he continues the unit's instructional sequence. If he does not reach criterion, his responses, are analyzed to determine the type(s) of error.

General adaptive model. The first adaptive concept sequence, termed general adaptive, prescribes a predesigned instructional program which follows the results of the initial test to determine if the learner is committing a classification error. This model regulates the learner's instructional sequence as he progresses toward the terminal objective of a given unit of instruction. After the initial evaluation, each learner's sequence of instruction is modified according to the individual response patterns. For example, learners who overgeneralize on the beginning segment of the task would be presented higher probability instances with increased prompting. The number of intermediate evaluations is determined by the concept difficulty. Some concepts may use only one sequence of examples followed by an exam, which would provide remedial help for those with errors. Another unit might involve teaching several complex concepts, requiring several intermediate tests and corrective frames.

Specific adaptive model. The second functional class of the ACA models (within-task variables) is utilized in the specific adaptive model. The learner would receive at the beginning of the instructional unit a presentation presumed to be optional followed by an intermediate evaluation. The within-task variables would be adjusted according to degree and type of error the learner is making at that point. Degree

refers to the measured severity of the error, that is, learners differ in the magnitude of incorrect responses. Whereas, in the general model the learner would be given a predesigned task to correct the error, the specific model would select a unique series of examples, in terms of difficulty and number of examples, to correct the degree (magnitude) of the error. Thus, if a learner was only making a slight overgeneralization, his corrective instruction would use just a few examples, while a learner making a gross overgeneralization would receive a large number of examples. In each case, the decision parameters would adjust to the type and degree of error.

Program sequence selection. In the various courses taught in schools, concepts vary in terms of complexity. In cases where concepts are difficult, it is desirable to design units with multiple entry points. In such situations pretask measures could be used to start the instructional presentation at a level of difficulty which is appropriate to an individual student. For complex concepts omitting a pretask measure to flag appropriate entry points into the program, optimization would be limited to the use of corrective frames to correct errors. The pretask measure, for example, allows low aptitude or highly anxious learners to enter a given program at a point which provides more instructional examples than a high aptitude learner. Both pre- and within-tasks adaptations are, thus, necessary in complex concepts. The use solely of the pretask measure, on the other hand, would offer a gross adaptation to the learner's characteristics. While the pretask procedure adapts the presentation to the learner's entering trait capabilities, the within-task makes the presentation self-modifying since it is continuously being adapted to the learner's current response pattern and state levels.

Interaction of task and learner characteristics. The pretask adaptive decision process which operates to enter a learner into the unit is based on an accurate evaluation of his repertoire of prerequisites to the unit. Preskill evaluation remains the most important component of the decision process. Other variables play a part in optimizing entry to the unit: aptitude indices, personological characteristics (e.g., anxiety, curiosity, etc.), and cognitive styles.

Once the learner has entered the unit at his optimal level, these characteristics will interact on a frame-by-frame level with task variables to produce a given net amount of learning; or, at intermediate levels, to produce a set state of progress. In order to optimize this progress, the instruction must adapt to this interaction between task and learner characteristics. This interaction can be continuously monitored by the computer through an appropriate analysis of the learner cumulative response record. The basis then for the specific adaptive decision process lies in a correct classification of the learner's successes and difficulties as they are evidenced over time within the unit. Only if the decision rules effectively deal with this aspect of the process will prescriptive measures (including both corrective and enrichment) be appropriate to an optimal progression through the unit. These decision rules may involve multiple factors, such as degree of correctness of the response, response latency, and cumulative indices of these two and other possible factors. The appropriate mix of factors which enter the decision rules will be heavily task-bound. The optimal combinations will be different from task to task and will depend directly on the given task's specific characteristics. This optimization, of course, will

evolve only through sustained formative evaluation of the decisional rules included in the model. In the meantime, a less effective approach can be taken. Broad decisonal parameters can be established on the basis of the limited research evidence in instruction and theory.

Instructional Model

This paper does not present the methodology for the decision/selection stages in designing the actual instruction task; other sources give in-depth descriptions of those procedures (Tennyson, 1972a; 1972b). The instructional model (Figure 1) is designed in accord with conclusions from research studies investigating those variables hypothesized to have a direct application to concept teaching.

1. Pretest. The first component of the instructional model is a pretest on the concept class to be taught which assesses the learner's entering behavior. The criterion-referenced testing evaluates minimum capabilities. If the learner meets criterion, he advances to step five, classification test; if not, he proceeds with step two.

2. Definition. In the study by Merrill and Tennyson (1972) on prompting effects, it was found that subjects performed significantly better on the learning task when given the definition which identified the relevant attributes of the concept class. The subjects became confused without the definition. The definition is a statement identifying the relevant attributes shared by a set of instances in a given class. Relevant attributes are enabling (or prerequisite) concepts assumed to be known by the student. Writing the definition requires a thorough analysis of the concept, usually resulting in simplication and reconceptualization of the class.

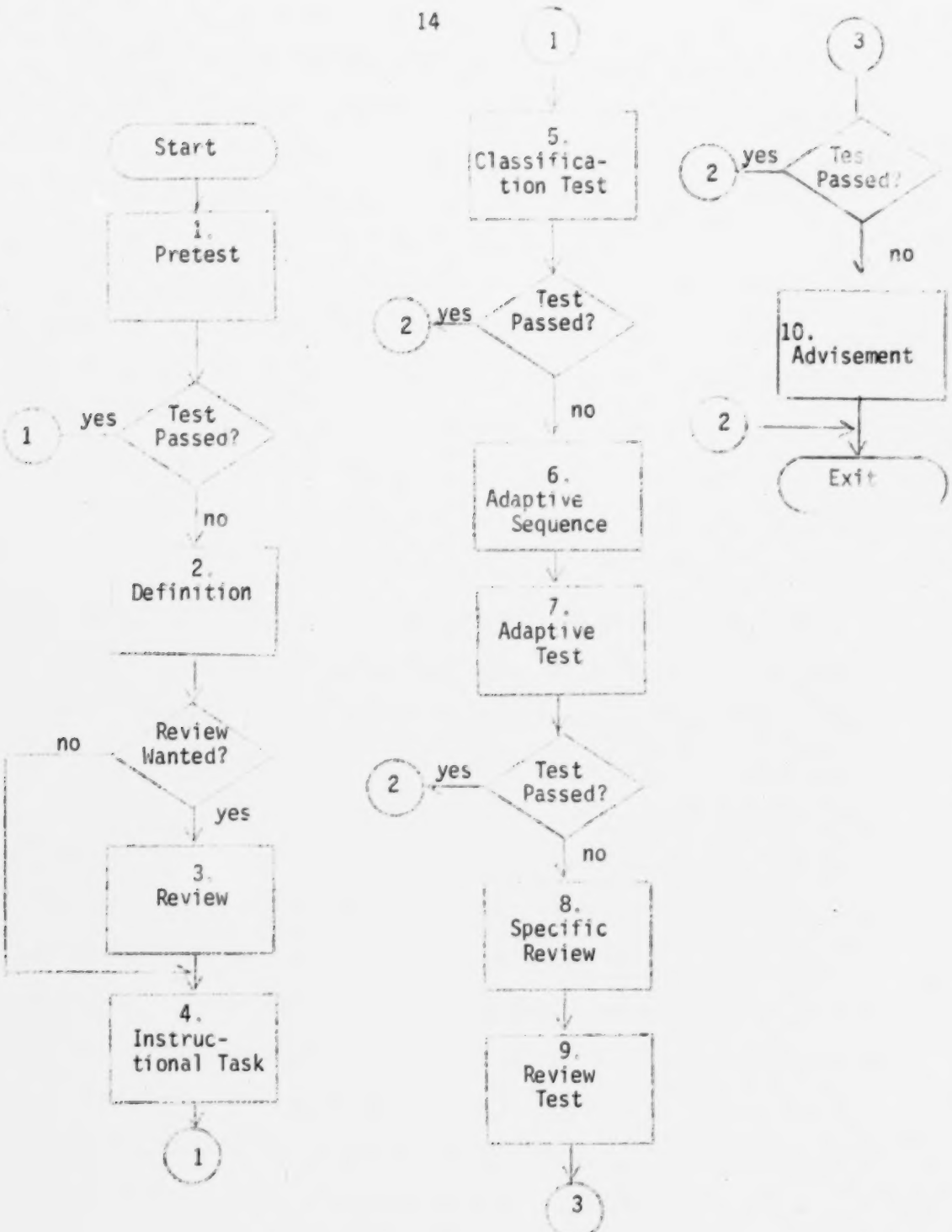

Figure 1.--Instructional model for concept acquisition.

3. Review. Merrill and Tennyson (1972) included a treatment condition which presented the prerequisite subskills of the concept being taught. The results did not indicate that this variable was a significant factor in task performance (ef. Merrill, 1965). However, certain blocking schemes of the data showed that subjects with low pretest scores who received a review did better on the posttest than similar subjects who did not receive the review. The review component is, therefore, included as an option.

4. Instructional task. Tennyson, Woolley, and Merrill (1972) developed an optimal group instructional strategy for teaching concepts. An optimal strategy consists of presenting examples and nonexamples to the student in such a way that the relevant attributes are clearly contrasted with irrelevant attributes. Task variables affecting learner processing of this information can be determined by four categories of procedures which are identified as stimulus similarity variables, prompting/feedback variables, sequence variables, and probability range.

A. Stimulus similarity variables include the following:

1. Matching of examples with nonexamples. An example is matched to a nonexample when both share identical or very similar irrelevant attributes.

2. Divergent examples. An example is divergent from another example when the corresponding irrelevant attributes are different. Examples which share the same irrelevant attributes are said to be convergent.

B. Prompting variables include the following:

1. Presenting a definition which identifies the relevant attributes (step 2 of the model).
2. Using various devices to identify the relevant attributes embedded in examples presented in the task.
3. Explaining why an example is an example or a nonexample is not an example.

C. Sequence variables include the following:

1. Simultaneous presentation of examples and nonexamples (Figure 1).
2. Optimally organized sequence.

D. Probability range includes the following:

1. High probability - those examples and nonexamples correctly classified by one-half of the subjects.
2. Low probability - those examples and nonexamples not correctly classified by one-half of the subjects.

These four task variables are manipulated into an example set (Figure 2). According to the concept paradigm, two examples should be paired (divergent) so that they differ as much as possible in their irrelevant attributes. Within the same simultaneous presentation, two nonexamples are presented which are matched to their respective examples by having irrelevant attributes as similar as possible. This relationship of examples and nonexamples is designed to focus the learner's attention on the relevant attributes. In the investigation by Tennyson (1972b) on the effect of nonexamples in acquistion, it was shown that subjects not receiving nonexamples responded randomly on the posttest, while subjects receiving nonexamples responded as hypothesized.

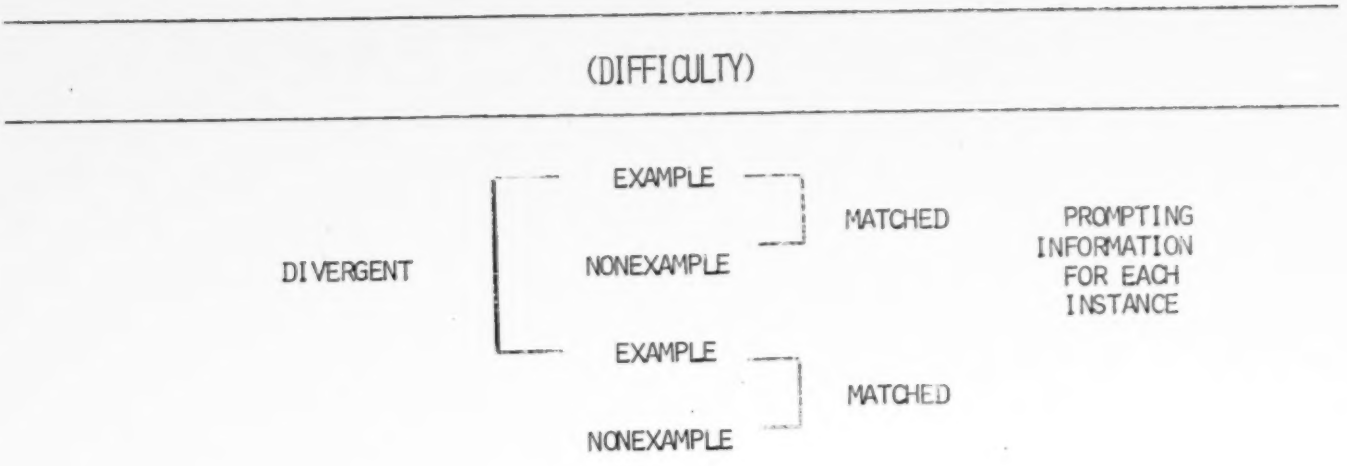

Figure 2.--Relationship of examples and nonexamples in concept acquisition.

Prompting is used in the example sets to explain why an instance is an example or why it is not an example. The subject matter determines the type and amount of prompting necessary. Example sets range in difficulty from easy to hard (Tennyson & Boutwell, 1972). Depending on the adaptability of the program and the hardware, the instructional sequence could have multiple entry points and student control over exit. Entry in the instructional unit could be determined by student profile data to individualize on trait and state variables.

5. Classification test. Tennyson, Woolley, and M. D. Merrill (1972) designed a posttest which was capable of determining the degree and type of classification error the subject was making at the conclusion of the instructional task. The test examined the subject's scoring patterns four different ways to see if he had an overgeneralization, an undergeneralization, or a misconception of the concept class (cf. Markle and Tiemann, 1970). Construction of the classification test follows the same procedures as outlined for the instructional task, except that the instances are randomized. The task presentation is expository, that is, the student is told whether an instance is positive or negative; while the classification test is inquisitive, that is, the student is not told the nature of the instances. Students meeting criterion on this test are finished with the lesson. Students not passing the classification test proceed to the next step where they receive remedial instruction based upon the type of classification error they made on the test.

6. Adaptive sequence. Concepts which are simple would require only specific review if a student fails the classification test. For concepts that are complex it is possible to identify the type of student error if

criterion is not met (Tennyson, et al., 1972; Tennyson, 1972b). Two basic levels of adaptation are possible, general and specific. In the general adaptive sequence learners would be classified into one of the three error categories. For each category an optimal group instructional task is given to correct the error. For example, if a learner overgeneralizes, a specific program designed to correct that classification error would be given. The corrective programs would be:

A. Overgeneralization. For learners who overgeneralize, the general adaptive procedure would be to select instances of easier difficulty than normally would be used in a standard example set sequence. Also, an increased level of prompting is given for each instance.

B. Undergeneralization. This error indicates that the student failed to identify difficult examples. To correct this, the example sets would begin with harder instances than used in the instructional task. The sequence would basically concentrate on difficult example sets.

C. Misconception. Since the subject seems to be focusing on some irrelevant attribute, the divergency of the examples would be expanded so that common irrelevant attributes are practically eliminated.

In all three corrective programs the students in each error category would receive the same modified sequence.

Specific adaptation is similar to the general adaptive condition in that adaptation is made according to type of error, but the corrective

procedures also are individualized according to the degree of error. The degree of error is determined by the number of errors of a given type. A learner who makes many overgeneralization errors would be given easier instances than a learner who makes few overgeneralization errors. The specific adaptive sequence also would increase prompting in a controlled situation so that no learner is either overloaded or insufficiently instructed.

7. Adaptive test. This test is designed to evaluate the effect of the corrective sequence. Test items would reflect the type of error to be corrected. It would not be a comprehensive test unless that degree of error was committed. Passing this test would exit the learner from the program. Failing again, the learner would receive one further level of remedial instruction.

8. Specific review This form of correction has a long history in the field of programed instruction. Remediation is specific to the item missed. Again the problem's degree of difficulty determines amount of corrective review. After this component of instruction a final test is given.

9. Review test. A standardized test similar to the classification test is administered. A learner failing to this point indicates that he learned almost nothing from the instructional task. In such a case this review test again assesses his ability to perform at criterion. If the learner meets criterion, he exits; if not, a continuation in the course is decided.

10. Advisement. In complex courses it is possible that some students will have difficulty with certain concept lessons. In such situations,

a decision can be made: drop the course or continue with another lesson and reschedule this lesson for a later date. The learner's individual cumulative profile is a major factor in the decision process (Bunderson, 1971).

Summary

As proposed, the ACA models may become an integral part of computer-based and conventional media approaches to concept presentation and review. Given this high-frequency of utilization, the models should provide for a significant savings in instructional time and improved concept retention. As operational features, the following benefits of the application of the ACA models are proposed: (1) The pretask variables of the ACA models are adaptable to individual learner trait characteristics. Premeasured conditions would assist in the assignment of learners to appropriate entry points within the instructional tasks. Such decisions would provide for residual savings in instructional costs by allowing high aptitude learners to finish courses earlier or to receive enrichment training. Individualized assignment of low aptitude persons to appropriate instruction has shown in research results to increase efficiency. (2) The within-task variables are designed to select instructional materials based on a learner's state characteristics. In a concentrated learning environment individual performances fluctuate so that premeasures do not always indicate accurate assessments of current capabilities. These within-task variables make the presentation self-modifying in that it is continuously being adapted to the learner's current response pattern and state levels. (3) Three additional payoffs are: (a) if the ACA models are computer based, each learner would have immediate access to adaptive instructional materials; (b) instructional

theory concerning media, feedback, knowledge of results, sequencing, role of examples, type of display, etc. can be designed into the adaptive individualized packages; and (c) a more precise prediction of the necessary media and materials should improve the cost effectiveness.

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